Distributed: Technical Division mills (appleton) X

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

CREEP BEHAVIOR OF BOXES AND CORRUGATED BOARD. PART 2. EFFECT OF BOX DIMENSIONS AND EDGEWISE COMPRESSION STRENGTH ON BOX STACKING LIFE

Project 1108-30

Report Four

A Preliminary Report

to

TECHNICAL DIVISION
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

September 21, 1966

TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

CREEP BEHAVIOR OF BOXES AND CORRUGATED BOARD. PART 2. *EFFECT OF BOX DIMENSIONS AND EDGEWISE* COMPRESSION STRENGTH ON BOX STACKING LIFE

SUMMARY

This study has for its purpose the development of information regarding the long-term load-carrying ability of corrugated board and boxes. This report summarizes an analysis of the differences in stacking life exhibited by the various box samples included in the study.

The results to date indicate that:

1. There is a large and significant difference in stacking life between the various box samples. At constant load, the box sample giving the highest stacking time exceeds the performance of the poorest sample by 30 or 40 to 1 as shown below:

Load Ratio	Stacking Life, day		
	Composite	Box 2408	Box 2457
0.75	7.3	1.5	43.1
0.70	22.0	3.4	130
0.625	113	22.7	666

2. The differences in box stacking life appear to depend in part on the box perimeter and depth as well as the combined board caliper and edgewise compression strength. In general, the lower the perimeter the higher the stacking life. Conversely, the higher the caliper, edgewise compression strength, or box depth, the higher the stacking life. As is evident from 1 above, these factors may cause large differences in box stacking life. These conclusions were somewhat surprising and certain of the trends, particularly the effect of depth, are

not fully understood. Because they are based on a limited array of box sizes and constructions, the relative importance of the four factors is somewhat uncertain.

3. Taking these factors into account results in an expression of the following type (see Fig. 4):

$$\text{Log } t = 8.9618 - 9.30R - 0.646(Z/d)(Z/h)^{0.5}/P_m$$

where

$\underline{t}$ = box stacking time, days

$\underline{R}$ = applied load ratio

$\underline{Z}$ = box perimeter, in.

$\underline{d}$ = box depth, in.

$\underline{h}$ = combined board caliper, in.

$\underline{P_m}$ = C.D. edgewise compression strength, lb./in.

Therefore, even at constant $\underline{R}$, two boxes may give quite different stacking lives depending on their dimensions and construction.

4. It is speculated that these factors influence stacking life because they are related to the tendency of the box panels to bow under load. If the degree of bowing is large, due to large panel sizes and lower weight construction, the force required to hold the panel in the bowed form may be relatively low. This would shift load to the vertical edges and result in shorter time to failures, at the same applied load ratio, as compared to a box where little bowing occurs.

5. While these laboratory stacking tests are far removed from actual warehouse stacking performance at this stage, they can eventually be of assistance in the manufacture and design of boxes, partitions, or inner supports. The effects of the latter items and the contents on stacking life have been largely unexplored.

6. The above results imply that double-wall boxes, if not too large, would give longer stacking lives than single-wall boxes. This is believed to be in agreement with the findings of other investigators.

7. These results are based on a small number of box sizes, flutes, and constructions. While any large test program to confirm and extend these results may be too costly, a limited study involving a few additional box constructions would help clarify the importance of the properties involved in 2. In such a study, the applied loads should be selected so as to avoid excessively long time durations.

8. As noted in past work, the variability in box creep failure lives is large and seems to be explained by the variability in conventional box compression tests. Reductions in box compression variability would appear to be of significant importance to stacking strength.

9. The analysis described above may be an important step in relating short column creep life to box creep life. Past efforts in this area were blocked by the large differences in box creep life — differences which now seem explainable in terms of box dimensions, etc.

INTRODUCTION

The failure as a function of time of boxes exposed to constant loads during warehousing is a major use hazard for corrugated boxes. It is well known that a corrugated box subjected to warehouse stacking will support only a small fraction of the box compression strength for a prolonged period of time. For this reason, a study is in process to provide information relative to the warehouse stacking (creep) characteristics of corrugated boards and boxes.

While the results are not complete because of the long-time intervals involved, the results to date are summarized in this report. This should facilitate use of the information and permit changes in emphasis of the experimental program where it appears desirable.

A limited review of the literature may be found in Report Two.

In Reports Two and Three it was noted that certain of the box samples appeared to exhibit significantly longer stacking lives than other samples. This trend has continued. The analysis in this report suggests that box dimensions and combined board properties influence stacking failure life as well as the applied load.

In the previous reports it was observed that the box failure lives obtained in the study were considerably greater than would have been anticipated based on the literature. As a result, with the exception of tests in progress, the lower load ratio tests were discontinued because of the prohibitively long times involved.

Efforts were made in Reports Two and Three to develop equations to fit the creep deflection vs. time curves. If the path of the creep curves could be predicted from conventional short-term compression tests, it should be possible to

a) estimate box failure time from the intersection of the creep deflection-time curve with the critical box deflection, or

b) estimate the time required to reach any specified deflection level which might be associated with damage to the contents.

This approach is difficult in theory and complicated by the wide variability in box failure life and creep deflection. It is hoped that these problems can be overcome in the future.

MATERIALS

The box samples shown in Table I are under test in this study. The top-load compression results for the boxes were summarized in Report Two.

TABLE I

BOX SAMPLES

Sample No.	Flute	Series	Dimensions, in. (l x w x d)	Z, in.	Weight, lb./M ft.^{2}	Caliper (h), in.	P_m, lb./in.	D_x, lb./in.	D_y, lb./in.	$\sqrt{D_x D_y}$, lb./in.	Flat Crush, p.s.i.	M	N
2406	A	200	16x12.25x9.5	56.5	130	0.203	51.1	199	100	141	34.7	1.95	6.58
2407	A	200	21x17.5x19	77.0	129	0.206	42.2	239	89	146	27.7	1.85	7.39
2408	A	200	23.5x23.5x19	94.0	131	0.206	45.7	213	98	144	31.4	2.32	8.23
2430	A	200	23.5x14x12	75.0	140	0.198	51.9	228	100	151	35.3	2.35	9.03
2456	A	175	13.25x6.62x12.5	39.8	135	0.190	34.3	177	61	104	28.6	1.35	3.70
2457	C	350	12.25x12.25x19.8	49.0	351	0.192	74.4	266	134	189	39.1	0.53	1.63
2510	C	275	16x12x18.5	56.0	177	0.168	59.8	--	--	--	42.3	0.93	2.83
2497	B	200	15.38x10.25x11.8	51.2	124	0.106[a]	45.9	60	27	40	35.2[a]	2.09	4.86
2498	B	275	17.88x16x11.4	67.8	176	0.125	63.5	--	--	--	45.8	2.19	6.36
2511	B	175	15.5x10.25x14.4	51.5	116	0.113	39.6	--	--	--	43.3	1.93	4.65

[a] Average of tests in printed and unprinted area.

[b] Symbols: Z = perimeter; h = caliper; P_m = edgewise compression

D_x, D_y = M.D. and C.D. flexural stiffness

$M = Z^2/P_m d$

$N = (Z/d)(Z/h)^{0.5}/P_m$

DISCUSSION OF RESULTS

BOX FAILURE TIME AND DEFLECTION *VS.* APPLIED LOAD

The creep failure lives for the boxes are shown in Tables II and III and Fig. 1. The regression lines shown in Fig. 1 were obtained by fitting lines of common slope to the data for each sample using IBM covariance program 6.0.032. (Note: The differences in slope between samples were not statistically significant.)

The technique yielded equations of the following type

$$\log t = \log a - 9.51R \qquad (1)$$

where

t = time, days

R = applied load ratio

a = a constant dependent on box sample — see Appendix I. Note: Log a corresponds to the intercept in a linear equation and is, therefore, a measure of the separation of the regression lines for the individual box samples.

As may be noted, Samples 2408 and 2457 differed most in stacking life. Using the curves shown in Fig. 1, the results in Table IV were obtained. The tremendous differences in stacking life at constant R in Fig. 1 or Table IV are obvious.

To determine if the differences in life between samples were significant, an analysis of variance (ANOVA) was carried out at the 0.625, 0.70, and 0.75 load ratios using the data in Table II. As in Report Three, the analyses were carried out using stacking times expressed in (1) days, and (2) transformed to logarithms. The logarithmic transformation is believed to be appropriate because (1) the logarithm of failure time is related to load ratio, and (2) the wide deviations in the

TABLE II

SUMMARY OF BOX CREEP RESULTS

Applied Load Ratio	Specimen No.	Failure Time, days Sample 2406 A-200	Sample 2407 A-200	Sample 2408 A-200	Sample 2430 A-200	Sample 2456 A-175	Sample 2457 C-350	Sample 2497 B-200	Sample 2498 B-275	Sample 2510 C-275	Sample 2511 B-175
0.75	1	0.22	0.44	1.15		6.46	17.74	5.35	0.89	4.88	1.49
	2	0.47	32.08	1.21		4.16	9.36	7.49	2.46	13.89	3.27
	3	0.50	15.49	1.39		0.03	26.10	0.25	3.11	50.60	4.78
	4	0.32	0.70	1.07		0.24	153.20	0.26	6.22	10.39	0.16
	Av.	0.38	12.13	1.20		2.72	51.60	3.34	3.14	19.94	2.42
0.70	1	270.6	33.4		over 196	33.1	62.6	8.9	127.0	234.4	10.9
	2	19.6	40.6			132.7	243.2	53.8	15.9	over 136	3.6
	3	20.0	41.7			79.5	over 357	9.5	35.7	49.1	10.3
	4	4.5	15.2			47.6	over 136	4.0	35.2	over 73	18.6
	Av.	78.7	32.7			73.2	199.7[a]	19.0	53.4	141.8	10.8
0.675	1	30.5	87.9								
	2	62.1	76.4								
	3	38.4	222.4								
	4	20.4	over 141								
	Av.	37.8	129.0								
0.625	1	33.8	15.8	16.5	29.8	115.4	72.6	19.9	248.3	320.7	62.6
	2	4.8	13.6	79.6	62.9	167.4	over 758	7.7	160.4	81.7	63.0
	3	155.7	95.9	13.1	90.1	655.9	200.6	140.6	214.3	over 66	210.4
	4	115.4	93.8	2.6	545.8	577.9	405.8	101.5	263.0	over 53	246.7
	Av.	77.4	54.8	28.0	182.2	379.2	359.2[a]	67.4	221.5	201.2	145.7
0.575	1	over 479	over 479			over 659	over 659	315.9	over 669	over 348	202.4
	2							over 349			
	3					over 479					
0.55	1	113.3	366.6	129.3		over 756					
	2	114.5	387.4	20.6		over 759					
	3	174.4	769.9	199.2							
	4	243.6		over 469							
	Av.	161.4	507.9	116.4							
0.50	1		344.0								
	2		578.0[a]								
	3		728.9								
	Av.		550.3								

[a] Includes results for one or more boxes which have not failed.

TABLE III

COMPARISON OF BOX CREEP DEFLECTIONS PRECEDING FAILURE WITH MAXIMUM DEFLECTION IN THE BOX COMPRESSION TEST

	Deflection, inch									
	Sample 2406	Sample 2407	Sample 2408	Sample 2430	Sample 2456	Sample 2457	Sample 2497	Sample 2498	Sample 2510	Sample 2511
Max. deflection (box compression test), inch	0.59	0.64	0.67	0.61	0.44	0.93	0.38	0.45	0.45	0.35
Creep failure defl., inch[a]										
0.75 load ratio										
1	0.64	0.62	0.73		0.44	0.84	0.38	0.42	0.45	0.38
2	0.65	0.71	0.78		0.39	1.02	0.40	0.49	0.48	0.35
3	0.56	0.61	0.73		0.39	1.06	0.36	0.45	0.62	0.33
4	0.59	0.54	0.76		0.37	1.13	0.39	0.54	0.44	0.37
Av.	0.61	0.62	0.75		0.40	1.01	0.38	0.48	0.50	0.38
0.70 load ratio										
1	0.65	0.67			0.51	1.06	0.41	0.51	0.48	0.35
2	0.66	0.69			0.46	0.96	0.41	0.54		0.37
3	0.67	0.67			0.43		0.50	0.50	0.42	0.35
4	0.58	0.69			0.53		0.40	0.50		0.39
Av.	0.64	0.68			0.48		0.40	0.51		0.36
0.675 load ratio										
1	0.69	0.77								
2	0.66	0.70								
3	0.61	0.70								
4	0.54									
Av.	0.62									
0.625 load ratio										
1	0.63	0.67	0.62	0.61	0.44	0.99	0.38	0.58	0.51	0.33
2	0.63	0.56	0.77	0.68	0.49	--	0.38	0.48		0.36
3	0.70	0.68	0.74	0.61	0.52	0.95	0.43	0.52		0.40
4	0.66	0.64	0.76	0.69	0.53	1.05	0.42	0.52		0.39
Av.	0.66	0.64	0.72	0.65	0.49		0.40	0.52		0.37
0.575 load ratio										
1							0.44			0.36
0.55 load ratio										
1	0.60	0.63	0.78							
2	0.58	0.78	0.74							
3	0.54	0.53	0.76							
4	0.64									
Av.	0.59	0.65								
0.50 load ratio										
1		0.66								
2		0.74								
3		0.75								
Av.		0.72								

[a] The creep failure deflection is defined as the last recorded value of the box deflection prior to box collapse.

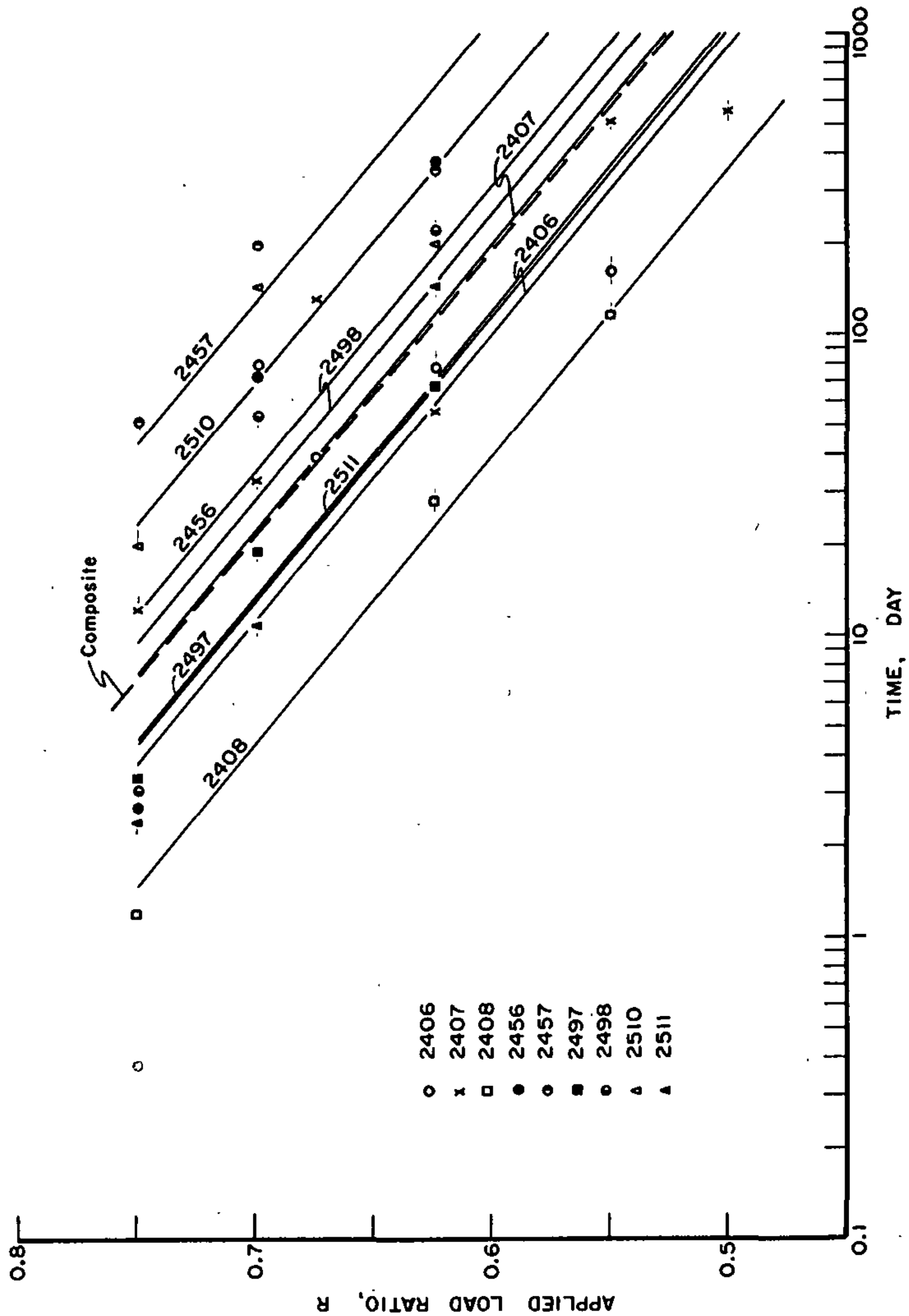

Figure 1. Relationship Between Box Failure Life and the Applied Load

individual data suggest that badly skewed distributions are present. As noted in Table V, the box samples of this study differ significantly in stacking life at all three load ratios in the logarithmic analyses. Even on the arithmetic basis, significant differences between samples were obtained at the 0.625 and 0.70 load ratios. This indicates that box stacking life is dependent not only on applied load but other factors.

TABLE IV

COMPARISON OF STACKING LIFE

Load Ratio	Composite	Stacking Life, day Box No. 2408	Box No. 2457	Kellicutt & Landt[a]
0.75	7.3	1.5	43.1	0.6
0.70	22.0	3.4	130	2.0
0.625	113	22.7	666	14

[a]From Fig. 6, Reference (1).

It was speculated that the differences in failure life at constant R between samples may be dependent on the relative tendency for the box panel walls to bow under load. As bowing occurs, the load required to hold the central regions of the panel in a bent condition would probably diminish. This would transfer load to the vertical edges. Therefore, boxes with large panel walls which bow at relatively low loads might be expected to exhibit shorter stacking lives than boxes having small panel dimensions where little bowing occurs under load. The stiffness, flexural or compression, of the panel relative to its dimensions should also be a factor since the tendency of the panels to bow will be dependent on their material properties as well as dimensions.

TABLE V

ANALYSIS OF VARIANCE OF DIFFERENCES IN STACKING LIFE BETWEEN BOX SAMPLES

Source of Variance	Degrees of Freedom	Arithmetic Analysis Mean Square	Arithmetic Analysis F	Logarithmic Analysis Mean Square	Logarithmic Analysis F
		0.625 Load Ratio			
Between lots	8	67,730.0	2.44[a]	0.8239	3.46[b]
Within lots	27	27,730.0		0.2382	
		0.70 Load Ratio			
Between lots	6	16,396.0	3.01[a]	0.7314	4.18[b]
Within lots	21	5,441.0		0.1751	
		0.75 Load Ratio			
Between lots	8	1,100.1	1.86	1.9499	4.30[b]
Within lots	27	591.5		0.4531	

[a]Significant at the 5% level.
[b]Significant at the 1% level.

To investigate this hypothesis, the relationship between the constant (log $\underline{a}$) in Equation (1) for each box sample and various panel dimensions and material properties was studied. The best relationships obtained are illustrated in Fig. 2 and 3. As may be noted, good correlations were obtained using the following equations:

$$\log a = 8.878 - 0.168\ Z^2/P_m d \qquad (2)$$

$$\log a = 9.105 - 0.648\ (Z/d)(Z/h)^{0.5}/P_m \qquad (3)$$

where

$\underline{Z}$ = perimeter, in.

$\underline{P_m}$ = C.D. combined board edgewise compression, lb./in.

$\underline{d}$ = box depth, in.

$\underline{h}$ = caliper, in.

$\underline{a}$ = factor in Equation (1) [varies with box sample]

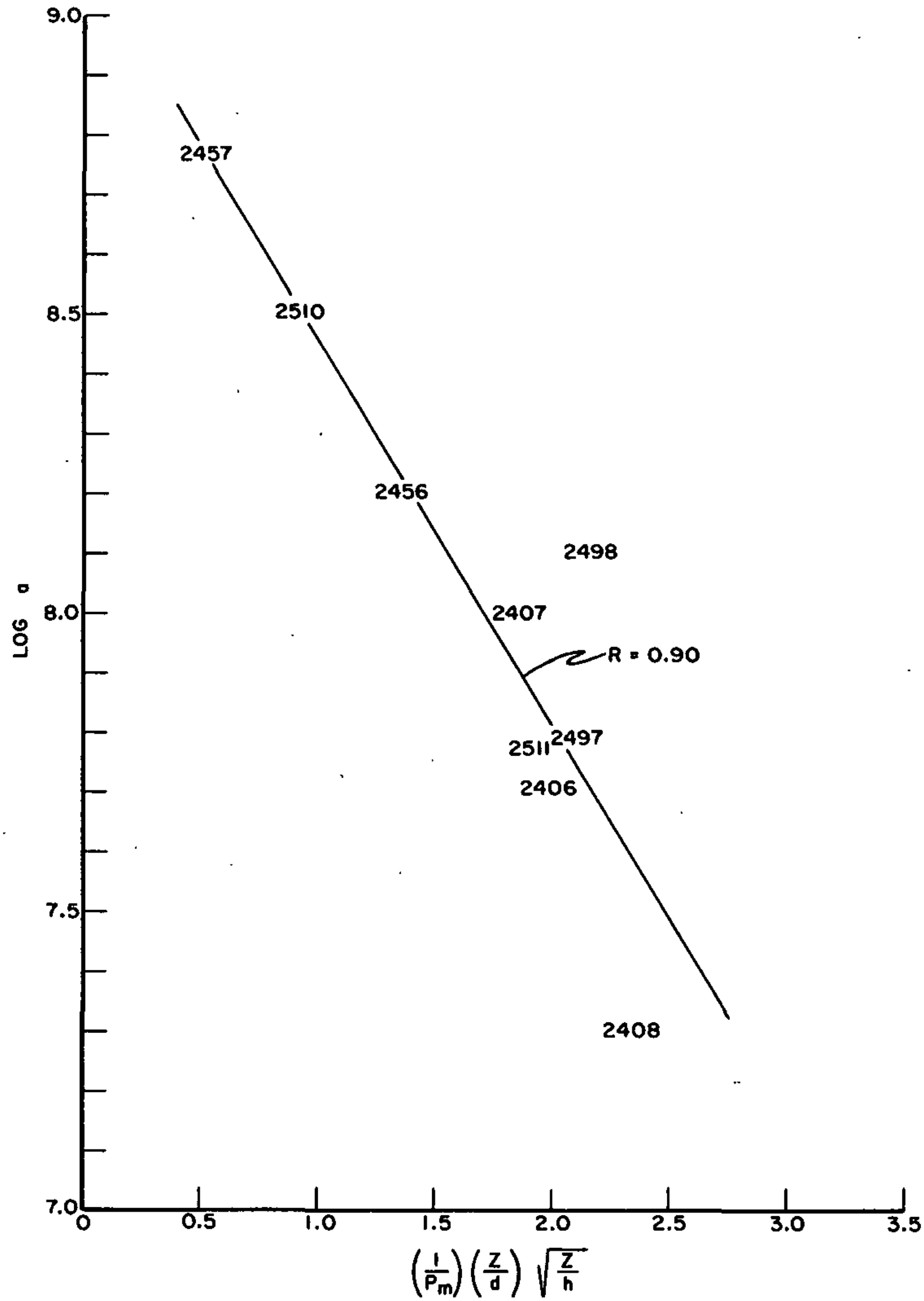

Figure 2. Relationship Between the Box Creep Life Intercept (Log a), Box Dimensions, and Edgewise Compression Strength

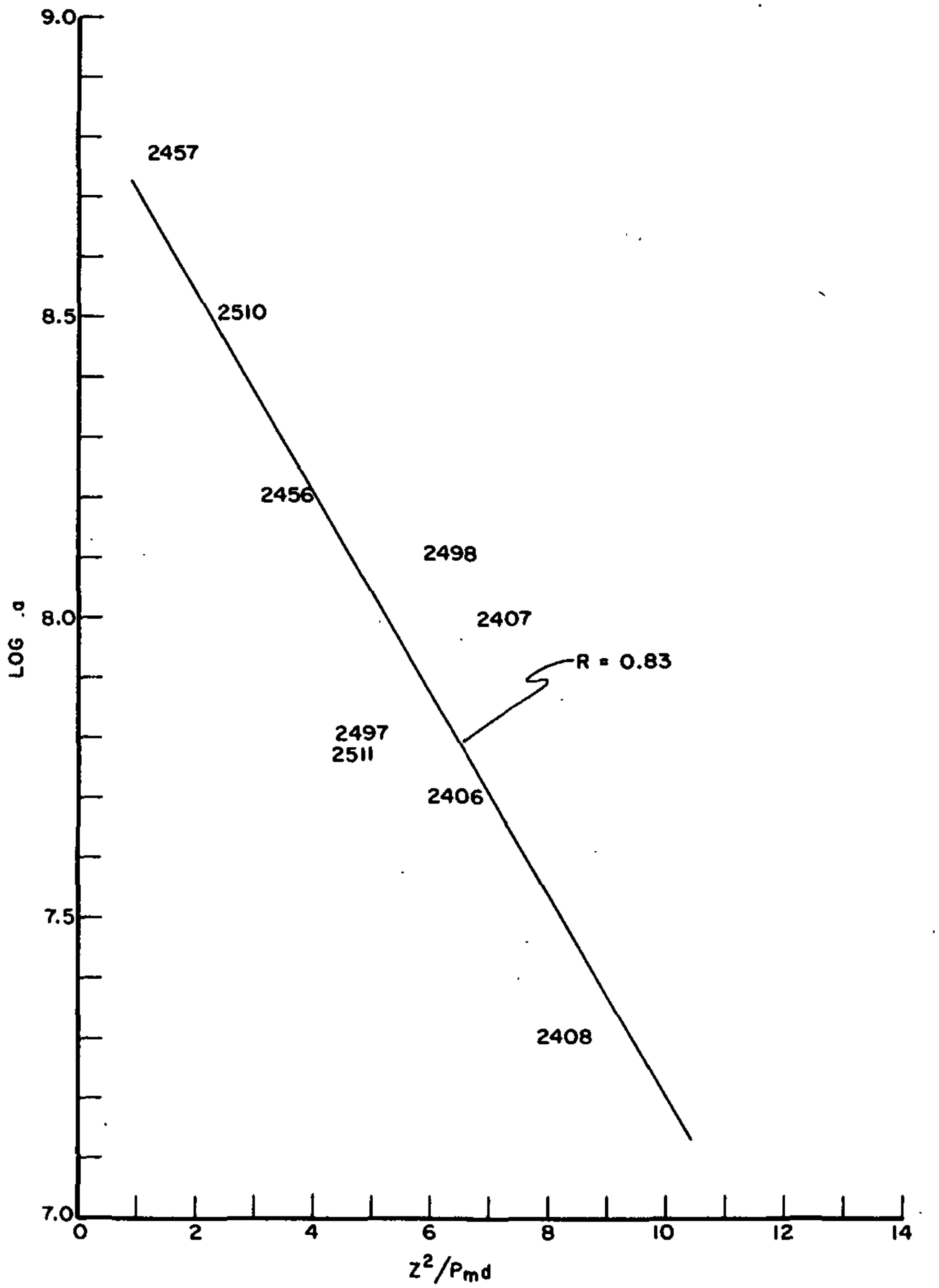

Figure 3. Relationship Between the Box Creep Life Intercept (Log a), Perimeter, Depth, and Edgewise Compression Strength

These results confirmed that box stacking life was dependent not only on the applied load but also on box dimensions and edgewise compression strength.

To supplement the above, two-factor multiple correlations were performed using the box stacking life data in Table II. Various combinations of perimeter, depth, P_m, and caliper were employed as second factors.

As may be noted in Table VI, the use of a second factor improved the multiple correlation coefficient — thus indicating that better predictions of average stacking life would be obtained. In most of the cases studied, the second factor is statistically significant at the 5 or 1% level.

The best correlations were obtained using Equations (5) or (6). These equations are shown below:

$$\log t = 9.0765 - 9.85R - 0.156\ Z^2/P_m d \tag{5}$$

$$\log t = 8.9618 - 9.30R - 0.646(Z/d)(Z/h)^{0.5}/P_m \tag{6}$$

where t = time, days, and the other factors are defined on page 12.

The equations primarily differ in that Equation (6) incorporates caliper as an additional factor. Caliper is not believed to be a dominant factor; however, there is some theoretical basis for its inclusion since it markedly influences bending stiffness.

The inclusion of depth as a factor was based on the correlations involving log a vs. various factors. Graphical analyses of the several factors involved and their combinations indicated that the depth factor was of importance. As it appears in the equations, the implication is that the higher the depth, other factors constant, the better the stacking life. This result was unexpected.

TABLE VI

RELATIONSHIPS BETWEEN BOX STACKING LIFE, APPLIED LOAD AND OTHER FACTORS

Equation No.	Regression Constants[a]		Constant	"t" Test[c]		Correlation Coefficient
	Factor 1	Factor 2		Factor 1	Factor 2	
4	-8.57R	--	7.3629	--	--	0.752
5	-9.85R	$-0.156Z^2/P_m d$	9.0765	8.30[c]	3.82(1%)	0.843
6	-9.30R	$-0.646(Z/d)(Z/h)^{0.5}/P_m$	8.9618	8.71[c]	4.66(1%)	0.867
7	-8.62R	$-0.00014Z^2/P_m h^2$	7.8177	6.78[c]	2.44(5%)	0.800
8	-9.55R	$-0.0048Z^2/P_m$	8.4280	7.21[c]	2.51(2%)	0.802
9	-8.59R	$-0.0624(Z/h)^{0.5}$	8.5702	6.50[c]	1.82(10%)	0.781
10	-8.97R	$-0.217Z/d$	8.5609	7.28[c]	2.95(1%)	0.816

[a] Regression Equation: $\text{Log } t = a + bR + cX$

[b]

Symbol	Quantity
t	Time, day
R	Applied load ratio
Z	Perimeter, in.
d	Box depth, in.
h	Combined board caliper, in.
P_m	Combined board edgewise compression, lb./in.

[c] Significant at the 1% level.

[d] Level of significance in parentheses .

However, the correlations are based on a rather limited array of box sizes. As a result, the importance of depth may be overemphasized.

Because of the variability in failure life and the time consuming problems in obtaining data, it is difficult to empirically establish the importance of the several factors which may be involved. While the above equations give the best estimates of stacking life for the present data, limited future tests involving various box sizes and material combinations would assist in defining the more significant variables.

Equation (6) is graphed in Fig. 4. At a given applied load ratio $\underline{R}$, stacking life is shown at several arbitrary levels of the second factor — $\underline{M} = (\underline{Z}/\underline{d})(\underline{Z}/\underline{h})^{0.5}/\underline{P}_{\underline{m}}$. Taking the equation at face value, stacking life varies with the quantities in the second factor as follows:

1. The lower the perimeter, the higher the stacking life.
2. The lower the caliper, the lower the stacking life.
3. The lower the value of $\underline{P}_{\underline{m}}$, the lower the stacking life.
4. The lower the box depth, the lower the stacking life.

The Institute understands that Kellicutt at the Forest Products Laboratory has obtained longer stacking lives with double-wall boxes as compared to single-wall boxes. Items 2 and 3, above, are in agreement with this result. The perimeter trend also seems reasonable at this time while the influence of depth seems more questionable as discussed previously.

The values of $\underline{M}$ in Fig. 4 for the boxes of this study ranged between about 0.5 and 2.5. The large differences in stacking life over this range, due to the box dimensions and combined board strength, are apparent. Double- or

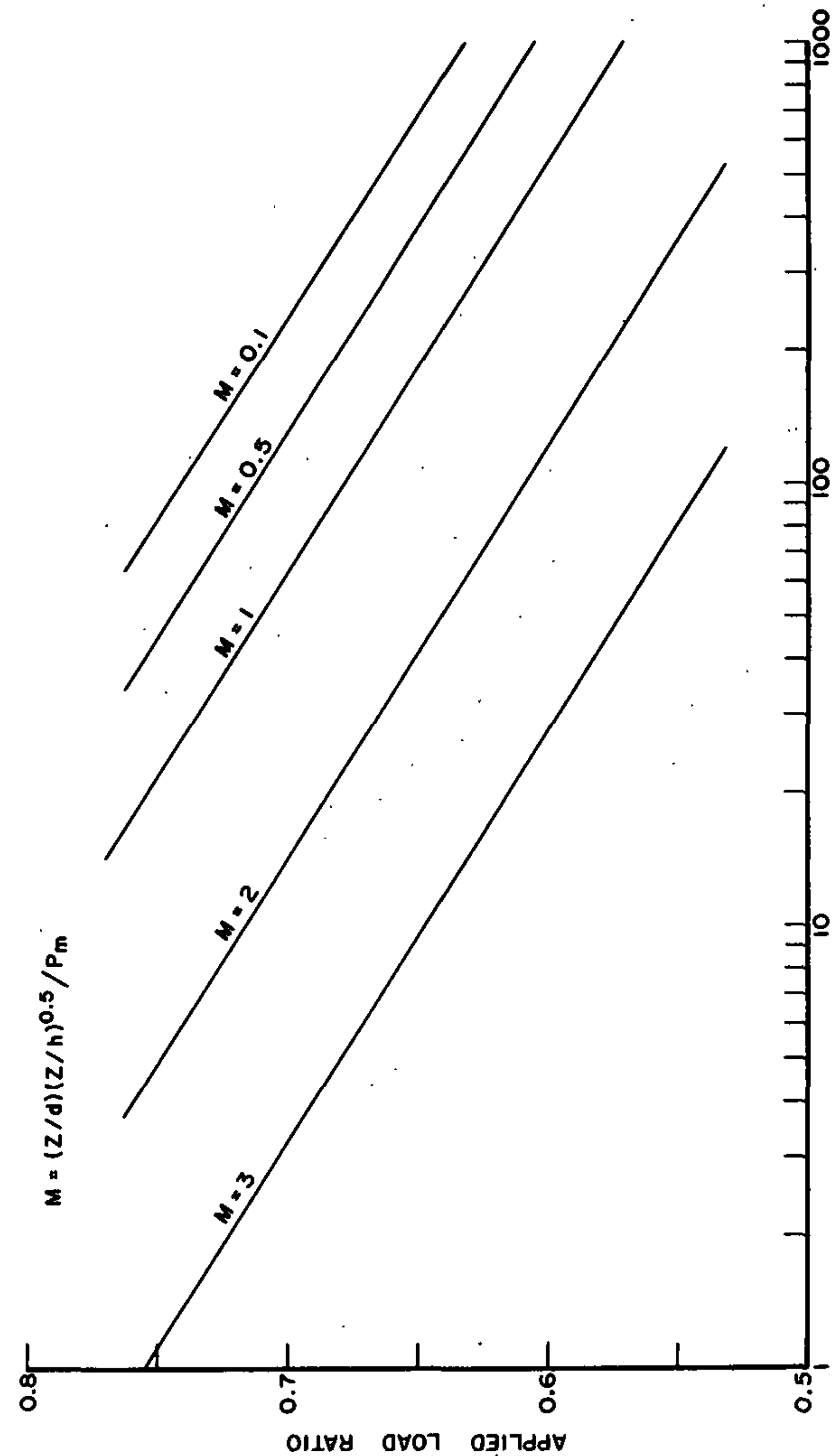

Figure 4. Relationship Between Box Stacking Life, the Applied Load, Box Dimensions, and Combined Board Properties

triple-wall boxes, if the dimensions were not large, might give lower values of M (less than 0.5) and correspondingly longer lives. This involves a considerable extrapolation of the present limited data.

The above analysis was concerned with the differences in stacking life between box samples. The variation in stacking times within samples is also of practical importance, since warehouse stacking complaints may occur because of the poor performance of a few boxes in the lot. In Report Two, an analysis of the within-sample variability was carried out which indicated that much of the variability in creep failure could be accounted for by variability in the short-term box compression test. For example, allowing for a variation in box strength of ± 2 standard deviations gave the following estimates of variation in box stacking life:

Load Ratio	Stacking Life, days		
	Av.	High	Low
0.75	11.5	58	1.53
0.625	54	234	10.8

In practical applications, it appears that box variability alone would force use of a substantial safety factor in box construction to obtain satisfactory performance under a given loading.

Whether this variability is inherent in the board or arises in the converting or boxmaking operation is an interesting question. For example, glue skips might be one source of variability; in which case efforts to obtain more uniformity in gluing could produce a superior box.

COLUMN FAILURE TIME AND DEFLECTIONS VS. APPLIED LOAD

To provide information relative to the creep behavior of corrugated board in compression, creep tests are in process on short columns of the type used in evaluating the edgewise compression strength – a basic factor governing top-load compression strength.

The creep failure lives and deflections are shown in Tables VII and VIII and Fig. 5. In general, the creep failure lives of the short columns varied with applied load in much the same manner as the boxes.

The columns appear to exhibit shorter lives than the boxes. Using the composite curve for the boxes in Fig. 1, the following comparison may be made:

	Life, days	
Ratio	Boxes	Column
0.75	7.3	0.56
0.70	22.0	3
0.625	113	32

The shorter lives for the columns may be due to the fact that the experimental arrangement for testing the columns makes use of two specimens. Failure occurs when the weaker specimen fails and this would be expected to result in a shorter average life for the columns as compared to the boxes. Some difficulties were also encountered in testing the B- and C-flute materials because of instability. An L-shaped specimen appeared to give satisfactory, vertical stability; however, the results with the L-shaped specimens at the higher load ratios may be somewhat lower than the previous A-flute results obtained with the conventional specimens.

TABLE VII

PRELIMINARY DATA ON COLUMN CREEP BEHAVIOR OF COMBINED BOARD

		Failure Time, days									
Applied Load Ratio	Specimen No.	Sample 2406 A-200	Sample 2407 A-200	Sample 2408 A-200	Sample 2430 A-200	Sample 2456 A-175	Sample 2457[b] C-350	Sample 2497[b] B-200	Sample 2498[b] B-275	Sample 2510[b] C-275	Sample 2511[b] B-175
Maximum Load lb./in.		51.1	42.2	45.7	51.9	34.3	74.4	45.9	63.5	59.8	39.6
0.75	1	1.41	0.17	0.16		1.06	0.79	5.18	1.08	0.02	0.05
	2	0.31	0.05	0.52		3.55	0.95	0.05	0.11	0.48	0.60
	3	1.51	0.16	7.01		0.08	0.33	0.04	0.13	0.06	0.01
	4	0.07	5.57			0.07					0.12
	5	1.01				0.36					0.07
	Av.	0.86	1.49	2.56		1.02	0.69	2.03	0.44	0.19	0.17
0.70	1	14.61	3.42	21.17		8.19	1.03	0.30	0.13	8.39	0.44
	2	6.75	3.63	1.37		4.00	9.55	6.90	0.02	1.02	4.47
	3	1.99				25.92			1.17	0.09	1.86
	4								0.02	0.02	1.55
	5								1.82		0.01
	Av.	7.78	3.52	11.27		12.70		2.64	0.63	2.38	1.67
0.686	1		0.56								
	2		2.26								
	Av.		1.41								
0.625	1	20.38	12.30	26.64	38.40[b]	30.75	45.97	99.08	1.71	30.97	2.58
	2	85.56	46.70	40.97	23.14	98.99	56.63	15.59	5.00	3.02	197.00[a]
	3	22.08	6.83	219.49	21.11	27.64	28.97	8.42	6.34	1.63	14.00[a]
	4	4.39	6.05	10.64	66.35	46.10	241.36	14.00[a]	124.00[a]	10.31	2.06
	5	11.07	14.44			92.03	13.66			3.00[a]	14.00[a]
	6		23.37			120.56			69.18		
	7		7.79								
	8		14.44								
	Av.	28.70	16.49	74.44	37.25	69.34	77.32	41.03	20.56	11.48	2.32

[a] Specimen has not reached failure and is still under test; these values are not included in any of the averages.

[b] Specimen shape is "L" shaped to obtain better vertical stability.

TABLE VIII

COLUMN CREEP DEFLECTIONS PRECEDING FAILURE

Applied Load Ratio	Specimen No.	Deflection, inch[a] Sample 2406	Sample 2407	Sample 2408	Sample 2430	Sample 2456	Sample 2457	Sample 2497	Sample 2498	Sample 2510	Sample 2511
0.75	1			0.031			0.025		0.030	0.024	0.035
	2	0.028		0.035			0.023	0.028	0.028	0.029	0.035
	3	0.013	0.034	0.037		0.025	0.062	0.023	0.030	0.032	0.021
	4	0.056	0.030			0.030					0.037
	5	0.046				0.015					0.027
	Av.	0.036	0.032	0.034		0.023	0.037	0.026	0.029	0.028	0.031
0.70	1	0.047	0.031	0.034		0.024	0.028	0.010	0.031	0.043	0.021
	2	0.029	0.032	0.040		0.028	0.040	0.021		0.033	0.035
	3	0.054	0.010			0.041		0.022	0.037	0.028	0.042
	4								0.021	0.021	0.026
	5								0.030		0.032
	Av.	0.043	0.024	0.037		0.031	0.034	0.018	0.030	0.031	0.031
0.625	1			0.027				0.023	0.028	0.045	0.020
	2	0.032			0.033	0.042	0.032	0.029	0.028	0.041	
	3	0.031		0.035	0.023	0.033	0.039	0.022	0.032	0.036	
	4	0.034	0.026	0.030	0.043	0.032	0.038			0.040	
	5	0.039	0.032			0.027			0.038		
	6		0.030			0.031					
	7		0.036								
	8		0.041								
	Av.	0.034	0.033	0.032	0.033	0.033	0.036	0.025	0.032	0.040	0.021

[a] The creep failure deflection is the last recorded deflection preceding the collapse of the column.

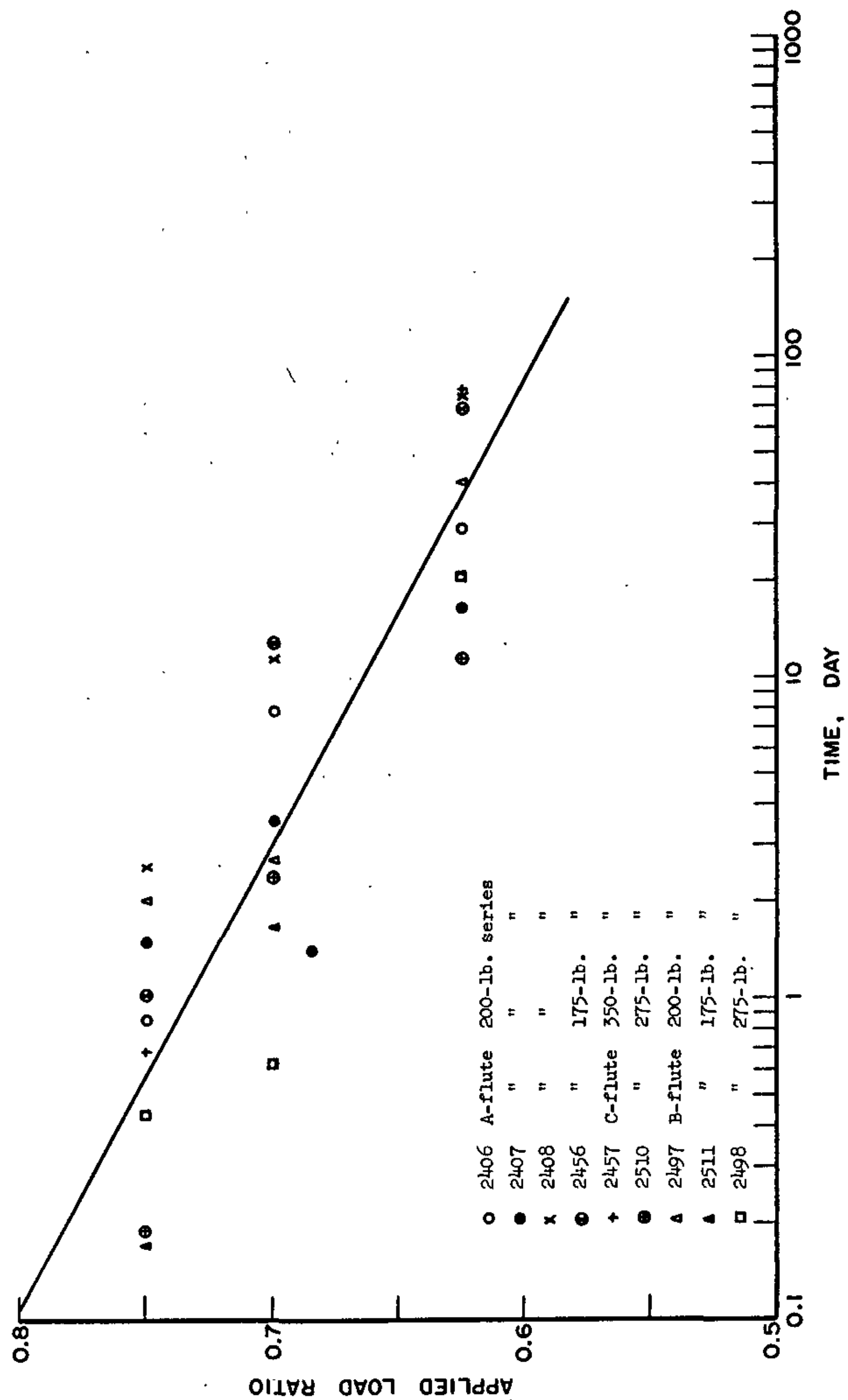

Figure 5. Relationship Between Applied Load and Column Creep Life

In the next report, an analysis of variance will be carried out on the column results to determine if significant differences occur between samples. If significant differences occur, they may be due to procedural effects or to inherent differences on board performance under long-term load.

In Report Two, it was noted that the column creep lives were not well related to the box creep lives. However, since the box stacking lives are influenced by box dimensions and material properties as shown previously, it is believed these additional factors must be taken into account in relating column and box creep life. An analysis similar to the box analysis summarized herein will be undertaken in the next report.

RECOMMENDATIONS FOR FUTURE WORK

The major objectives of the study are:

1. To relate box stacking performance to the creep characteristics of combined board.
2. To investigate procedures for predicting combined board creep behavior by accelerated test methods.
3. To improve combined board and box stacking performance.

The present study was designed to provide background information for Objectives 1 and 2. The experimental phase is nearing completion despite the unexpectedly long stacking which was encountered, and a complete analysis of the box and column results is planned.

Based on the literature, it was anticipated that box stacking life would be a function of only the applied load. The data to date indicate, however, that box stacking life is also affected by other variables, namely, box dimensions and combined-board properties. The distribution of box sizes and constructions in the present study were not planned with this eventuality in mind and, consequently, have limitations for determining the effects of the added variables. For this reason, the stacking resistance of a limited number of additional box sizes and constructions should be evaluated. These stacking tests should be limited to relatively short durations — perhaps 100 days — to complete the work in a reasonable period.

A second underlying premise has been that box stacking life in high humidities would also be affected only by the applied load referenced to the short-term compression strength in the particular atmosphere. The above results cast some doubt on this premise. A limited number of tests at high relative humidity employing the present or proposed boxes would serve to explore this possibility.

In general, accelerated stacking tests can be obtained by using high applied loads, high relative humidities, or combinations of the above. If a number of tests could be simultaneously initiated, the test could be terminated (a) after the failure of a predetermined number of specimens, e.g., 50% of specimens, or (b) by counting the number of failures after given periods of time under load. In either case, test times would be considerably shortened since there would be no need to wait for the longer lived specimens to fail. The development of a test procedure along these lines could materially assist stacking life evaluation.

Short of basic changes in the entire pulping and papermaking operations, the opportunities for improving stacking resistance may be in the following areas:

1. Improvements in conversion uniformity, particularly adhesion.
2. Boxmaking operations such as scoreline profiles.
3. The use of additives, impregnants, and coatings.
4. Internal stiffeners – partitions, posts, etc.

Investigations in these areas can be done most efficiently using the conventional short-term compression tests to screen out any promising approaches. Accelerated creep tests could be used to check the long-term load performance of the more promising approaches.

In addition to a complete analysis of the results of the current study it is suggested that the following additional studies be initiated:

1. Extension of the current work to a limited number of additional box constructions, including double-wall boxes. Testing would be performed at 50 and 90% R.H.
2. Investigation of methods of conducting accelerated box and combined creep tests.

EXPERIMENTAL OUTLINE

I. Extension of Present Box and Combined Creep Tests.

A. Materials: The following constructions and approximate box dimensions are suggested:

1. 350-lb., A-flute – 23x17x12 in.
2. 350-lb., B-flute – 23x17x12 in.
3. 175-lb., C-flute – 16x12x9 in.
4. 275-lb., C-flute – 20x15x15 in.
5. 350-lb., double-wall – size to be determined
6. 500-lb., double-wall – size to be determined

B. Stack time durations: Applied loads should be selected to restrict durations to no more than 100 days in so far as possible.

C. Test atmospheres:

1. 50% R.H. and 73°F.
2. 90% R.H. and 73°F. (limited to one or two load ratios).

D. Analysis: In conjunction with the current data the analysis would be directed toward:

1. Developing relationships between box stacking life, box dimensions and board construction, including the effects of humidity.

2. Developing relationships between combined board column creep life and box stacking life, including the effects of humidity.

II. Investigation of Methods of Conducting Accelerated Combined Board Creep Tests.

A. Materials: From Part I, above, supplemented by material and data from the current study.

B. Development of accelerated creep life test procedure for box or column.

1. Test atmosphere: 50 or 90% R.H.

2. Load: Selected to give median values no greater than about 10 days.

C. Analysis of results:

1. Median values for the box and/or column results at 50% R.H. or 90% R.H. will be analyzed to relate median life at a high load ratio to average or median life at lower load ratios.

2. Procedures for evaluating test precision and comparing sample medians will be evaluated.

LITERATURE CITED

1. Kellicutt, K. Q., and Landt, E. F. Forest Products Laboratory, Report No. 1911, September, 1958.

THE INSTITUTE OF PAPER CHEMISTRY

W. J. Whitsitt

William J. Whitsitt
Research Associate

R. C. McKee

Robert C. McKee
Chairman, Container Section

APPENDIX I

COVARIANCE REGRESSION LINE CONSTANTS

Sample No.	Log a[a]	Estimated Values of Failure Time, days	
		R = 0.625	R = 0.75
2406	7.70658	57.9	3.75
2407	8.00538	115.2	7.46
2408	7.29972	22.7	1.47
2456	8.20375	182.0	11.8
2457	8.76718	665.9	43.1
2497	7.78815	69.9	4.52
2498	8.10102	143.6	9.30
2510	8.49608	356.7	23.1
2511	7.77132	67.2	4.35
Composite	7.99521	112.6	7.29

[a] Regression form $\log t = \log a - 9.51R$.